

A study of the influence of the stochastic process on the synchrotron oscillations of a single electron circulated in the VEPP-3 storage ring

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Abstract

Last year measurements of the single electron longitudinal motion were performed. The pictures of the synchrotron oscillations for a long time were obtained and handled. The results of the experiments demonstrate the diffusion in the phase space caused by quantum fluctuations of synchrotron radiation.

1. Introduction

The longitudinal bunchlength is one of the important properties of the bunch of charge particles in accelerators and many theoretical and experimental methods are developed to calculate and measure its value for the various conditions. Using universally adopted techniques, we can obtain only the envelope of the set of particles, but the question about the state and behavior of a single particle inside the bunch remains open.

We have investigated the radiation of a single electron, circulated in storage ring VEPP-3, in order to obtain information about its state [1,2]. The aim of the first part of the experiments was the estimation of the longitudinal localization length of a single particle inside the bunch [1]. The interpretation of the result is the following: electron longitudinal "size" is essentially less than the natural bunchlength. This result is appropriate to the point of view of quasiclassical theory, describing a particle in a storage ring as a point-like oscillator.

The next step was the investigation of longitudinal motion of a single electron in a storage ring. Using the photon counting method we have observed the process of the synchrotron oscillations at the discrete moments of photocounts. Furthermore, experimental data were handled to get information about the main features of this process [2].

In this paper we describe the further experiments.

2. Description of the experiment and data handling method

The description of our measurement scheme in detail may be found in the previous paper [2]. We registrate the undulator radiation from a single electron, circulated in the VEPP-3 storage ring with revolution frequency 4 MHz, modulated by the synchrotron frequency (about 1 kHz). We use the photomultiplier in the photon counting mode. We measure the delay between the photocount and the first reference pulse from the RF System of VEPP-3 (which corresponds to the equilibrium particle). Another circuit gauges the time interval between the photocounts. The delay and the time interval are written into the memory of the intelligent CAMAC controller. The small part of the dependence of delay versus time is shown in Fig. 1. The full time of the experiment (about 3.2 s) is limited (compared with our previous experiments) we use transputer T-414 on the base of the intelligent CAMAC controller and suitable software, developed at our institute. Now we have 2 Mb memory size for experimental data (i.e. 450 000 events or full time of experiment is about 1 minute). Other attractive property of this computer scheme is its high speed (about 8 MIPs) and now the real speed of registration is defined by measurement circuits.

Thus, the result of the measurement is the array of couples which comprises the dependence of the longitudinal coordinate of an electron on the time and it was necessary to choose the algorithm for data handling and to obtain the amplitude and the phase of the synchrotron oscillations. Note, that the distribution of the time intervals between photocounts is Poissonian and this fact compli-

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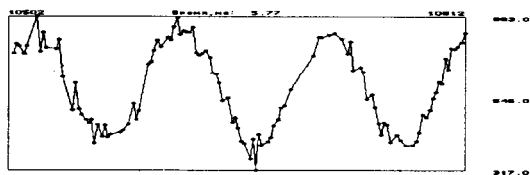


Fig. 1. The small part of the measured dependence.

cates the possibility of applying standard methods of handling (for example, digital filters or FFT methods). On the other hand the error points are present in the experimental array (due to parasitic illumination and the dark current of the photomultiplier) and we have to exclude them.

The spectrum of the process under study is shown on Fig. 2 and at first approach we can suggest that obtained dependence is sinusoidal with slowly varying amplitude and phase.

$$x(t) = A(t) \sin(\Omega_0 t + \phi(t)), \quad (1)$$

where Ω_0 corresponds to the maximum of the spectrum.

In order to exclude error points in the experimental array we approximate the small part of dependence under study by the empiric expression (1), using the least-squares method. Usually we choose the part of sequence with time duration about a few periods of oscillation. It was shown in Ref. [2] that the duration of about one period is “optimal”. Getting the rms error of the fitting sinusoid, we exclude all points with a deviation of more than 1.75 rms errors. After this “cleaning” procedure, 15 percents of the experimental data are accepted.

To get the values of the amplitude and the phase of oscillation, we use a more precise method. The dependence of amplitude A versus instantaneous frequency is shown in Fig. 3. The bow of the points distribution on this figure corresponds to the nonisochronosity of oscillations and is approximated by the well-known expression for the simple pendulum in first approach:

$$\Omega_1 \approx \Omega_0(1 - A^2/16).$$

Due to the nonisochronosity and local fluctuations of frequency, the accuracy of the approximation (1) depends on the choice of the Ω_0 . Taking into account this fact, we

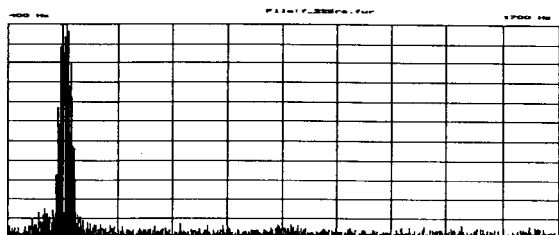


Fig. 2. The spectrum of the synchrotron oscillation process. Frequency span: 400 Hz to 1700 Hz.

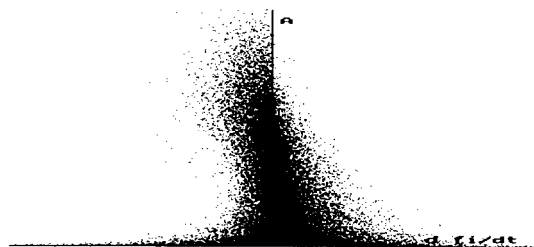


Fig. 3. The dependence of the amplitude versus instantaneous frequency.

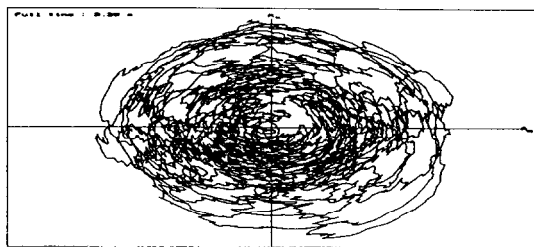


Fig. 4. Trajectory of a single electron in polar coordinates. Elapsed time: 3.28 s

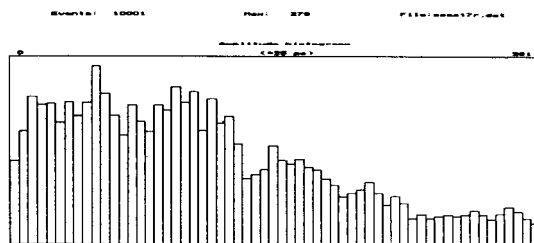


Fig. 5. The amplitude histogram.

also find the instantaneous frequency for the approximating sinusoidal, and minimize the least-squares aim function also for Ω_0 , using a numerical algorithm (gold-crosection method). After that, we represent Ω_0 as a sum of two parts: the average frequency Ω_a , which is constant for given realization, and the frequency fluctuations component.

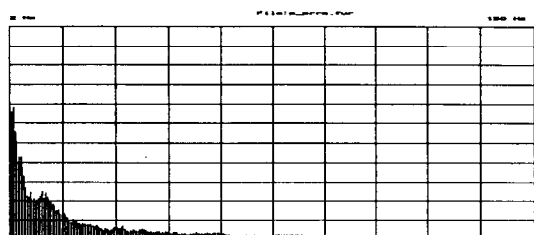


Fig. 6. The spectrum of the amplitude. Frequency span: 2 Hz to 150 Hz.

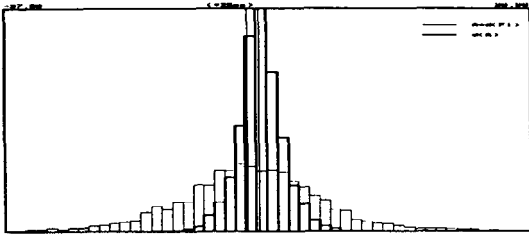


Fig. 7. The distributions of the changes. The amplitude is drawn in bold lines.

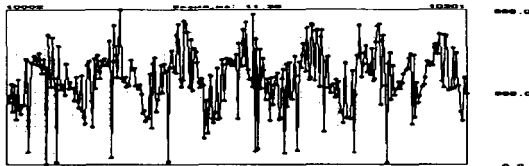


Fig. 8. The small part of the measured dependence (two electrons).

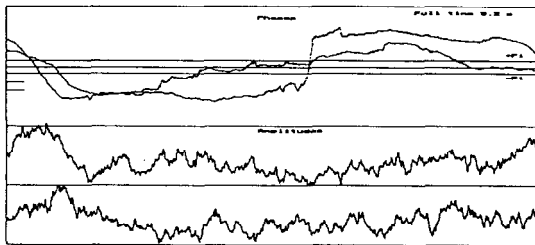


Fig. 9. Amplitudes (bottom part) and phases (top part) of synchrotron oscillations of two electrons. Elapsed time: 3.2 s.

3. Results

Applying this algorithm to the consequent parts of the delta, we obtain the trajectory in polar coordinates $A(t)$ and $\phi(t)$, where the frequency of rotation of coordinate axes is Ω_a (Fig. 4). The full time of electron motion is about 3 s.

The distribution of amplitude is shown in Fig. 5 and all

of the absciss intervals on the histogram have the equal areas on the plane (A, ϕ) . An interesting feature of this distribution is a dip near the small amplitudes, that exists for all realizations.

The spectrum of amplitude (a Tukey window is used) is depicted in Fig. 6. The tail of the spectrum decreased as $1/\omega$.

We obtained the first changes of the stochastic process of the electron motion in the phase plane, radial: $\Delta A = A(t) - A(t + \tau)$ and azimuthal: $\Delta\phi(t) = A(t)(\phi(t) - \phi(t + \tau))$, where $\tau = 0.3$ ms. Distribution of the radial changes is always Gaussian. The third moment of the distribution of the azimuthal changes is not zero, due to nonisochronosity of oscillations (Fig. 7). The characteristic correlation time of the changes is about 1 ms.

We also investigated the motion of two electrons simultaneously. The part of the experimental data is shown in Fig. 8. Using a algorithm similar to the above-mentioned one, we separate the experimental points of each electron in the pair and get the time dependences of amplitudes and slow phases of the two electrons, which are shown in Fig. 9. Limits $+\pi$ and $-\pi$ in the phase dependence correspond to the full round trip of the electron trajectory around origin of coordinates.

Acknowledgements

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